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Extrasolar planets and brown dwarfs around A-F type stars ⋆

II. A planet found with ELODIE around the F6V star HD 33564.

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Abstract.
We present here the detection of a planet orbiting around the F6V star HD 33564. The radial velocity measurements, obtained with the ELODIE echelle spectrograph at the Haute-Provence Observatory, show a variation with a period of 388 days. Assuming a primary mass of 1.25 $M_\odot$, the best Keplerian fit to the data leads to a minimum mass of 9.1 M_{Jup} for the companion.

Key words. techniques: radial velocities - stars: binaries: spectroscopic - stars: early-type - stars: brown dwarfs - planetary systems

1. Introduction

Radial velocity surveys have lead to the detection of more than 150 planets during the past decade [1]. So far, they have been limited to solar and later-type stars ($\gtrsim$ F7), as it was thought that planets around more massive stars were not accessible to radial velocity techniques. They present a small number of stellar lines, usually broadened and blended by stellar rotation. However, we recently showed (Galland et al., 2005a, Paper I) that with a new radial velocity measurement method, it was possible to detect planets even around early A-type stars. Finding planets around massive stars is of importance, as this will allow us to test planetary formation and evolution processes around a larger variety of objects.

We have started a radial velocity survey dedicated to the search for extrasolar planets and brown dwarfs around a volume-limited sample of A-F Main-Sequence stars i) with the ELODIE fiber-fed echelle spectrograph (Baranne et al. 1996) mounted on the 1.93-m telescope at the Observatoire de Haute-Provence (CNRS, France) in the northern hemisphere, and ii) with the HARPS spectrograph (Pepe et al. 2002) installed on the 3.6-m ESO telescope at La Silla Observatory (ESO, Chile) in the southern hemisphere. The method, achieved detection limits as well as estimates of the minimum detectable masses are described in Paper I. We present here the detection of a planet around one of the objects surveyed with ELODIE, HD 33564. Section 2 provides the stellar properties, the results of the radial velocity fit and related comments. In Section 3, we rule out other possible origins of the observed radial velocity variations. Finally, we discuss the status of this system in the last section.

2. A planet around HD 33564

2.1. Stellar properties

HD 33564 (HIP 25110, HR 1686) is located at 21.0 pc from the Sun (ESA 1997). Stellar parameters such as mass $M_1 = 1.25^{+0.03}_{-0.04}\,M_\odot$, age $3.0^{+0.6}_{-0.3}$ Gyr, metallicity [Fe/H] = -0.12 are taken from Nordström et al. (2004). Rotational velocity $v \sin i = 12\,\mathrm{km\,s^{-1}}$, effective temperature $T_{\mathrm{eff}} = 6250$ K, and surface gravity $\log g = 4.0$ are taken from Acke & Waelkens (2004), see Table 1. These values are consistent with an F6V spectral type, commonly attributed to this star as e.g. in the HIPPARCOS catalogue (ESA 1997) or in the Bright Star Catalogue (Hoffleit et al. 1991).

An infrared excess has been detected at 60 μm toward HD 33564 (DM +79 169) with IRAS (Aumann 1985, Patten & Willson 1991), which suggested that this star could be a Vega-like star, surrounded by a cold (65 K) dusty circumstellar disk, remnant of the formation of the system. Indeed, some Spitzer results show that this infrared excess is due to a background galaxy and not to a circumstellar disk around HD 33564 (Bryden et al. 2006).

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⋆ Based on observations made with the ELODIE spectrograph at the Observatoire de Haute-Provence (CNRS, France).

[1] A comprehensive list of known exoplanets is available at http://www.obspm.fr/encycl/cat1.html

Table 1. HD 33564 stellar properties. Photometric and astrometric data are extracted from the HIPPARCOS catalogue (ESA 1997); spectroscopic data are from Nordström et al. (2004) and Acke & Waelkens (2004).

Parameter		HD 33564
Spectral Type		F6V
$v \sin i$	[km s^{-1}]	12
V		5.08
B-V		0.506
π	[mas]	47.66 ± 0.52
Distance	[pc]	21.0
M_V		3.47
[Fe/H]		– 0.12
$T_{\rm eff}$	[K]	6250
log g		4.0
M_1	[$M_\odot$]	$1.25^{+0.03}_{-0.04}$
Age	[Gyr]	$3.0^{+0.6}_{-0.3}$

2.2. Radial velocity measurements

By April 2005, 15 spectra have been acquired with ELODIE over a time span of 417 days. The wavelength range of the spectra is 3850-6800 Å. The typical exposure time was 15 min, leading to S/N equal to ~ 150. The exposures were performed with the simultaneous-thorium mode to follow and correct for the local astroclimatic drift of the instrument. The radial velocities have been measured using the method described in Chelli (2000) and Paper I. They are displayed in Fig 1. The uncertainty is 11 m s^{-1} on average. It is consistent with the value of 10 m s^{-1} obtained from simulations in Paper I by applying the relation between the radial velocity uncertainties and $v \sin i$ to HD 33564, with S/N values equal to 150.

2.3. Orbital parameters

The amplitude of the radial velocity variations is much larger than the uncertainties. The orbital parameters derived from the best Keplerian solution (Fig. 1) are given in Table 2. The residuals dispersion is 7 m s^{-1}. The eccentricity is 0.34. Assuming a primary mass of 1.25 M$_\odot$, the companion mass falls in the planetary domain, with a minimum mass of 9.1 M$_{\rm Jup}$. The orbital period is 388 days (separation of 1.1 AU).

Note that the maximum of the radial velocity variations could not be observed. The orbital period is close to one year and a long time will still be necessary to be able to cover the whole phase. To quantify the resulting uncertainty on $m_2 \sin i$, we tried several fits fixing different values for the eccentricity. We find that residuals are acceptable with values of this eccentricity between 0.28 and 0.40. The resulting minimum mass ranges then from 8.7 to 9.6 M$_{\rm Jup}$, hence an uncertainty of 6 % on the minimum mass corresponding to the best solution (given the primary mass).

Besides, this star was also observed with the CORAVEL spectrograph. The obtained radial velocities are constant over 4 years given uncertainties of 500 m s^{-1} on average. The radial velocity variations obtained with ELODIE have a semi-amplitude lower than 250 m s^{-1}, not detectable with CORAVEL.

Table 2. ELODIE best orbital solution for HD 33564.

Parameter		HD 33564
P	[days]	388 ± 3
T	[JD-2400000]	52603 ± 8
e		0.34 ± 0.02
γ	[km s^{-1}]	0.107 ± 0.006
ω	[deg]	205 ± 4
K	[km s^{-1}]	0.232 ± 0.005
N$_{\rm meas}$		15
$\sigma(O-C)$	[m s^{-1}]	6.7
$a_1 \sin i$	[10^{-3} AU]	7.8
f(m)	[10^{-7} $M_\odot$]	4.21
M_1	[$M_\odot$]	1.25
$m_2 \sin i$	[M$_{\rm Jup}$]	9.1
a	[AU]	1.1

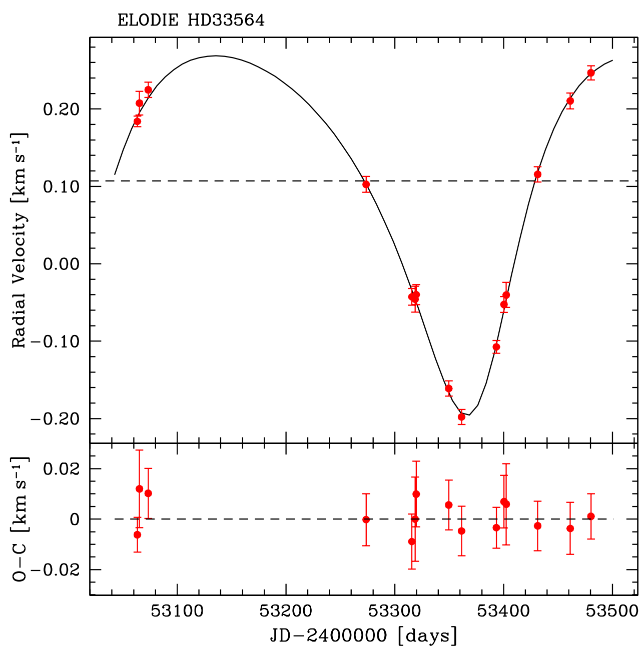

Fig. 1. Top: ELODIE radial velocities and orbital solution for HD 33564. Bottom: Residuals to the fitted orbital solution.

3. Ruling out other origins of the variations

3.1. A single star

HD 33564 is referenced as a double star, but the high difference between the proper motions of the two components indicates that they are probably not bound. Besides, the separation between the two components is larger than 6 arcsec, so that the flux from the secondary does not enter into the fiber of the spectrograph, even in bad seeing conditions. Hence, the spectra are not polluted by the secondary spectra. In both cases, the presence of the secondary is not responsible for the observed radial velocity variations of the considered component, HD 33564 A.

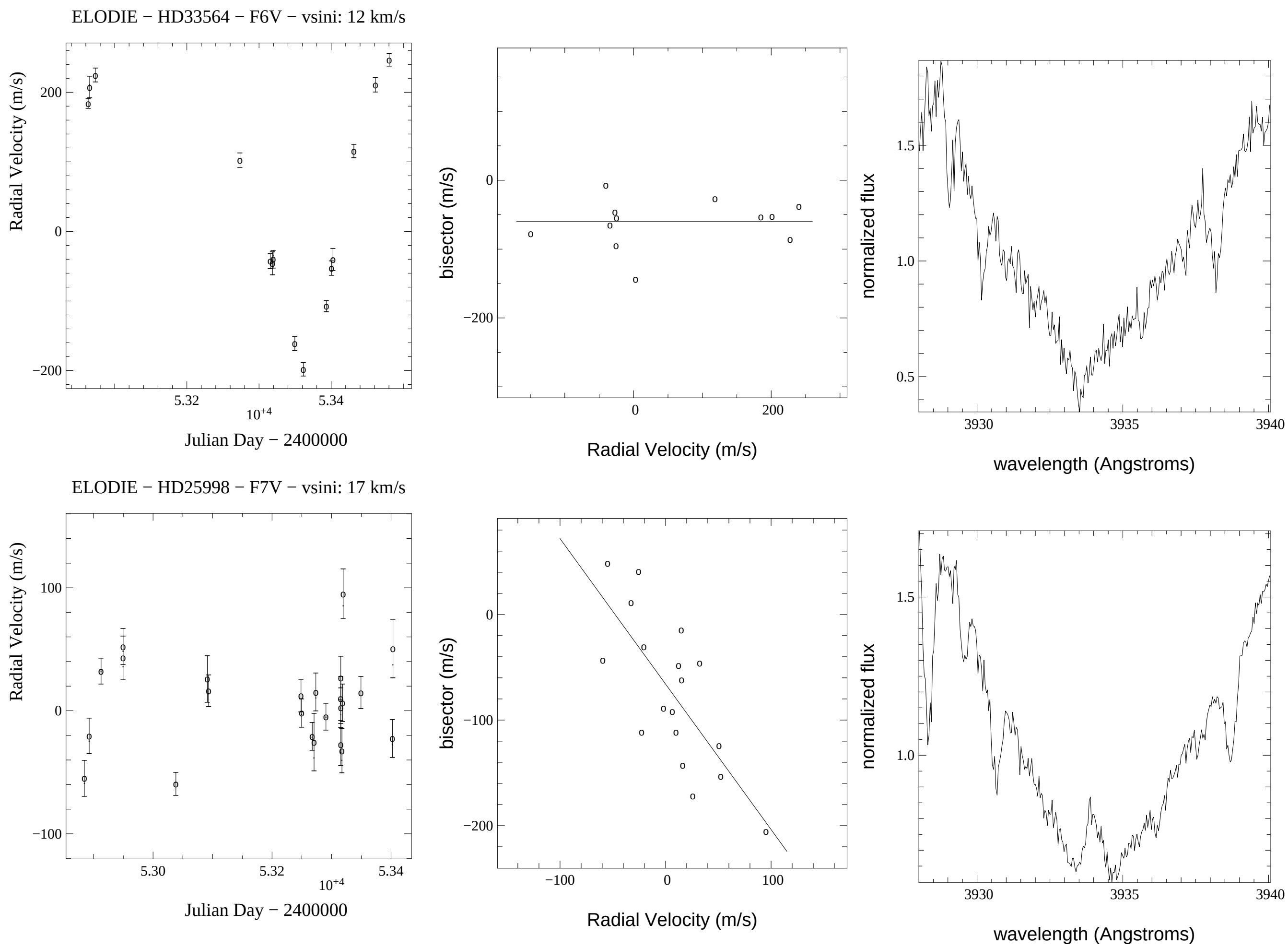

Fig. 3. Left: radial velocity measurements of HD 33564 (top) and HD 25998 (bottom): they are significantly variable. Center: the line bisector (see text) is not variable for HD 33564, while it is variable for HD 25998, in a similar range, and linearly related to the radial velocities. This is typical of the presence of spots, induced by stellar activity (Queloz et al. 2001a). Right: no emission in the Ca K line in the case of HD 33564, emission in the case of HD 25998.

3.2. A similar star constant in radial velocity

To rule out any possibility of artifact linked with the Earth orbital motion, we show in Fig. 2 the radial velocities of a similar star, close to HD 33564, but constant within the present level of uncertainties: HD 17948 is an F4V star with $v \sin i = 11\,\mathrm{km\,s^{-1}}$. It also belongs to our ELODIE survey. By April 2005, 5 spectra have been gathered for this star, with S/N equal to 136 on average. The typical uncertainty is $10\,\mathrm{m\,s^{-1}}$ comparable to the one obtained for HD 33564. The observed radial velocity dispersion of 8.4 $\mathrm{m\,s^{-1}}$ shows that star is constant over the 150 days of the measurement span.

3.3. An activity-quiet star

We show here that activity is not responsible for the radial velocity variations of HD 33564. First, the bisector shape of the lines is estimated on the cross-correlation function (inverse bisector slope) in the same way as in Queloz et al. (2001a). It is displayed in Fig 3, together with the one of a known active star (Gray et al. 2003) included in our ELODIE survey, HD 25998 (F7V, $v \sin i = 17\,\mathrm{km\,s^{-1}}$), for comparison. It is flat i.e. there is no correlation between the radial velocities and the shape of the lines for HD 33564. On the other hand, it varies linearly with the radial velocity in the case of HD 25998 (the slope value is -1.4), which is typical of spots induced by stellar activity (see Queloz et al. 2001a for further details).

Moreover, no emission in the core of the Ca II lines is observed (see Fig 3 for the case of the Ca II K line). The chromospheric flux in the Ca II K and H lines of HD 33564 has been measured by e.g. Gray et al. (2003), who gives an activity index $\log(R'_{HK}) = -4.95$, leading to the classification of HD 33564 as an inactive star. For comparison, the value of $\log(R'_{HK})$ is -4.47 in the case of the active star HD 25998. Hence, contrary to HD 25998, activity is not responsible for the radial velocity variations observed for HD 33564. This is also confirmed by the fact that the period of the radial velocity variations is much larger than the rotational period of HD 33564 (less than 7 days given its value of $v \sin i$).

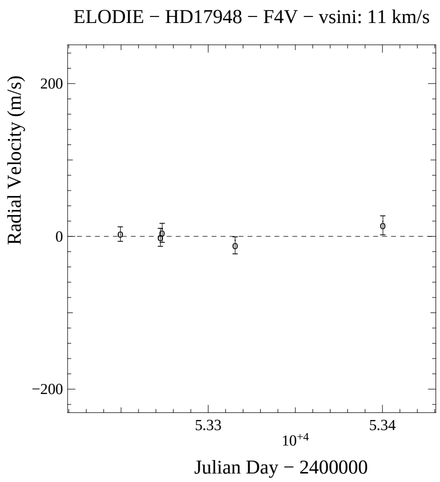

Fig. 2. ELODIE radial velocity data for HD 17948, a star constant in radial velocity (dispersion of 8.4 m s^{-1}), similar and close to HD 33564. The vertical scale is identical to the one in Fig. 1.

4. Status of the HD 33564 system

So far 16 stars with spectral type between F7 and F9 have been reported as hosting possible planets detected through radial velocities. HD 33564 is, to our knowledge, the earliest spectral type star around which a companion with $m_2 \sin i$ in the planetary domain has been announced. The reported $m_2 \sin i$'s range between 0.4 and 11 M_{Jup}. Four objects, namely HD 23596, HD 89744, HD 114762 and HD 136118, are found with $m_2 \sin i \geq 5\,M_{Jup}$ i.e. 8.0, 7.2, 11.0 and 11.9 M_{Jup}, respectively. The corresponding estimated planet-star separations are 2.7, 0.88, 0.37 and 2.3 AU, respectively. HD 33564, with $m_2 \sin i = 9.1\,M_{Jup}$ and a = 1.1 AU, falls in a similar (mass, separation) domain. Knowing the inclination of these systems would be very important for constraining planet formation models. If their true masses are found to be planetary, one may wonder how such massive planets could form and stand so close to their parent stars. Whether migration has occurred or whether the planets have been formed by gravitational collapse rather than by a scenario including accretion onto a solid core are possibilities that need to be investigated. The proposed idea that “the more massive the star, the more massive the planets hosted” is also very interesting. Studies on lower mass stars (Lin & Ida 2005) show such a trend, does it exist for A-F type stars?

Besides, we may emphasize the low value of the metallicity for HD 33564, which is not common among stars hosting planets. There is however no metallicity trend for the early-type stars with massive planets mentioned above.

5. Conclusions

We have presented here the first detection of a planet around one of the objects surveyed in our ELODIE program, HD 33564, an F6V star with $v \sin i = 12$ km s^{-1}. The best Keplerian solution derived from the radial velocity measurements leads to a minimum mass of 9.1 M_{Jup} and a period of 388 days, hence a separation of 1.1 AU.

This result is a first step toward the extension of the study of planet and brown-dwarf formation processes to stars earlier than F7. This is fundamental for a global understanding of the most interesting planetary formation mechanisms involved. For example, one of the question to be addressed is whether the planetary masses depend on the primary stellar masses: the more massive the star, the more massive the planets hosted ?

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These results have made use of the SIMBAD database, operated at CDS, Strasbourg, France.

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